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TECHNICAL NOTES

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No. 229

AN ALTITUDE CHAMBER FOR THE STUDY AND CALIBRATION OF AERONAUTICAL INSTRUMENTS

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Summary

The design and construction of an altitude chamber, in which both pressure and temperature can be varied independently, was carried out by the National Advisory Committee for Aeronautics at the Langley Memorial Aeronautical Laboratory at Langley Field, Virginia, for the purpose of studying the effects of temperature and pressure on aeronautical research instruments. Temperatures from +20°C to -50°C are obtained by the expansion of CO_2 from standard containers. The chamber can be used for the calibration of research instruments under altitude conditions simulating those up to 45,000 feet. Results obtained with this chamber have a direct application in the design and calibration of instruments used in free flight research.

Introduction

The difficulty in the design of instruments used in aeronautical flight research does not lie so much in the problem of designing proper mechanisms to indicate or record a series of variables as in the lack of knowledge of the characteristics of the instruments while undergoing large temperature changes which in some one particular test in the same flight may be as large as 60°C. Aeronautic instruments are in general subject to large temperature changes and for research problems exhibit errors of considerable magnitude as a result. The Aeronautic Instruments Section of the Bureau of Standards has done much valuable work on the study of temperature effects on standard airplane flight indicating instruments and on recording instruments and has found that for very accurate determination of altitude it is necessary that the instruments be calibrated under conditions duplicating the test.

Low temperature and low density both are conditions met with in the higher altitudes so it is absolutely necessary to know the temperature corrections of such instruments. It is being demanded more and more that instrument designers supply the needs for good aeronautical research instruments, thus it is quite obvious that in the development of new instruments the final working conditions under which they are to function must be simulated in the laboratory.

There are a number of methods available for obtaining low temperatures, all of which have their advantages and disadvantages. The requirements of a cooling medium which were duly considered in the selection of a proper refrigerating agent are as follows:

1. Proper temperature range.
2. Availability.
3. Low cost of refrigerant and of requisite equipment.
4. Safety and ease of handling.

After careful investigation in the light of the above properties, carbonic acid gas (CO_2) was selected as the refrigerant. CO_2 has the proper temperature range, its freezing point being $-57^{\circ}C$. It is a commercial product and as it is manufactured in large quantities is not expensive. On account of the small amount of CO_2 required (approximately 8 lb. per test) the expanded gas is allowed to escape to the atmosphere and the use of expensive compressor equipment with its consequent requirement of a skilfull operator is avoided.

General Description of the Altitude Chamber

The size of the altitude chamber as designed and constructed at the Langley Memorial Aeronautical Laboratory is such that it will accommodate the instruments most frequently used by the National Advisory Committee for Aeronautics in flight research. These are the single component recording accelerometer, the recording airspeed meter and statiscope, the recording altimeter, the control position recorder, etc.

The chamber is composed of an upper and lower section (Figs. 1 and 2). The leg supports are fastened to and are a part of the upper section; the lower section being movable in the vertical direction and counterbalanced by a suitable weight in the rear.

The upper section (Figs. 1, 3, and 4) supports and thermally insulates a circular cast iron plate p, which supports the instrument rest e, the air circulating blower n, the cooling coils m, the high pressure expansion valve g, the heat interchanger c, and the automatic relief valve b. All air and electrical connections pass through plate p, which forms the top side of the air-tight chamber. This cast iron plate was ribbed to prevent distortion, and has a thick annular ring finished to accommodate a standard 12-inch diameter glass bell jar.

The support for the instrument under test is triangular in form, constructed of 1/16 inch cold-rolled steel, and is held in place by three upright supports passing between the turns of the copper cooling coils and fastened to the iron plate with machine screws.

The blower that circulates the air around the cooling coils and the instrument is $4\frac{1}{2}$ inches in diameter by 3 inches long. The driving shaft r, of the rotor, passes up through the top of the cabinet, at which point it is connected to a 1/50 HP. Universal motor. It is suitably packed to prevent undue leakage of air from the outside during low chamber pressures.

The cooling coil consists of 30 turns of 3/8 inch O.D.

copper tubing having a length of 63 feet and furnishing 6 square feet of radiating surface.

The expansion valve extends through the iron plate and is connected to the copper coil by means of a fitting which also serves as a case for a resistance type thermometer element for the measurement of temperatures at the expansion valve.

On its way from the CO_2 tank to the expansion valve the high pressure line k passes through the heat interchanger. This latter is connected to the inner copper coil by means of a relief valve and a resistance type thermometer fitting; the former governs the pressure in the coils and the latter measures the temperature as the gas leaves the coils.

The heat interchanger consists of a 1-inch copper tube $5\frac{1}{2}$ feet long, extending to the outside of the chamber and surrounding the high pressure line on which are soldered washers 3/4 inch in diameter. These washers are spaced 1/2 inch apart and act as heat transfer fins.

An instrument panel is mounted on the top of the upper section in order that the operator may know the conditions existing within the chamber and coils at all times. There are on this board three galvanometers used in resistance type thermometer circuits and graduated in degrees centigrade, one voltmeter and two pressure gauges.

Three temperatures are measured: that of the CO_2 gas at the expansion valve and at the back pressure relief valve, and that of the air in the chamber. The voltmeter is used to check the voltage across the wheatstone bridge circuits of the resistance type thermometer, the voltage being maintained by means of a suitable rheostat place in series with the battery. The calibration curves of the galvanometers for use as indicating thermometers are shown in Fig. 5.

The pressure gauges indicate the pressure in the copper coils; two gauges are used more as a precautionary measure than to indicate the drop of pressure that may occur. It is very necessary to know that the copper coil is clear at all times and not blocked or clogged with foreign matter that may be in the CO_2, so one gauge is placed at the expansion valve and the other at the back pressure relief valve.

The high pressure gauge shown in Fig. 2 is in the high pressure CO_2 line just before it enters the cabinet and denotes the condition of the CO_2 in the tank or container indicating when the supply is nearly exhausted.

The lower section of the cabinet (Fig. 6) houses the inverted glass bell jar; the open edge of the bell jar being ground to a plane surface. When this section is raised (Fig. 1), the jar comes in contact with the lower edge of the iron plate and forms an air-tight joint. This seals the chamber. A suitable observation window d is placed in one side of the cabinet to enable the operator to observe any visible change or read any instrument that may be placed within.

The glass bell jar is lagged with corkboard insulation 4 inches thick at its thinnest section. At these low temperatures corkboard was found most satisfactory as it cost no more than a good quality of lumber, works easily, is efficient and does not absorb moisture. The curve of loss of temperature through cork insulation with time is given in Fig. 7.

Adjacent to the altitude chamber (Fig. 2), the CO_2 tank is supported in a wooden rack. The valve end of the tank is down, in order to force liquid to the chamber expansion valve. This rack is so arranged with lever mechanisms that it can be raised from the floor and supported on a platform scale. The amount of CO_2 used in any test can then be conveniently and quickly measured.

On the opposite side of the tank rack is a small low temperature calibrating outfit without means for pressure variation. This is used for calibrating small instruments such as glass tube thermometers and electrical resistance thermometer elements. It is convenient for cooling any object that may be immersed in alcohol or gasoline and has no greater dimensions than $2\frac{1}{2}$ inches diameter and 6 inches long. This apparatus consists of a copper coil immersed in an alcohol or gasoline bath. The container is made double-walled with a dead air space which can be evacuated in order to make the insulation very effective. A stirrer driven by a small 1/200 HP. motor circulates the bath liquid around the coils and object undergoing calibration. Temperatures slightly lower than those reached in the altitude chamber can be obtained with this low-temperature equipment.

Operation

In the operation of either the altitude chamber or the low temperature bath, no great skill is required. Any one familiar with laboratory equipment can after a few trials make very satisfactory tests. One person can conveniently operate the chamber and take readings for the usual run of calibrations if the rate of drop desired is not more than two degrees Centigrade per minute. If more than one instrument is to be calibrated and the rate of drop required is greater, two persons are necessary.

The cycle of operation is as follows: The CO_2 liquid in the high pressure line to the expansion valve is at approximately 900 lb./sq.in. at room temperature, the pressure being a function of tank temperature. It is reduced to 75 lb./sq.in. in the copper cooling coil, the pressure being held constant by the back pressure relief valve. The liquid in passing through the expansion valve evaporates, the heat of vaporization being drawn from the copper coils, thereby cooling them. The temperature of the gas corresponding to a back pressure of 75 lb./sq.in., is $-56.4^{\circ}C$. The temperature at the expansion valve under these conditions drops very nearly to $-56.4^{\circ}C$. The temperature of the saturated gas corresponding to atmospheric pressure is nearly -85° but if the CO_2 is allowed to reduce from the high pressure to atmospheric pressure in the coils, the corresponding low temperature freezes the following liquid as it passes through the expansion valve and the resulting snow clogs the valve and stops operation until the valve thaws out. For this reason it is necessary to prevent the back pressure dropping below that corresponding to the temperature of the freezing point of the CO_2.

After the gas passes the relief valve, it enters the interchanger and any cooling effect still left in the gas as it passes to the atmosphere is absorbed by the fins on the high pressure line and imparted to the incoming high pressure liquid. Any pre-cooling of the liquid before expansion causes that much more cooling effect to be applied to the copper coils within the bell jar.

In the actual operation of the chamber, after the instrument under test is placed on the instrument support and air and electrical connections are made and the bell jar is brought in place, the regulation of the high pressure expansion valve is all that is required from the operator to control the temperature throughout the test. The temperature gradient is entirely a function of the amount the valve is opened. Excessive opening of the valve should not be attempted unless the efficiency of the chamber may be sacrificed, because the gas will pass through the circuit without having had time to absorb heat from the coils.

In case temperatures lower than approximately $-56^{\circ}C$ are desired, a by-pass valve in the copper coil circuit may be operated and the CO_2 allowed to expand to atmospheric pressure. This can be done only for very short intervals of time because the expansion valve and coils will become clogged with CO_2 snow and automatically prevent the passage of more CO_2.

Any desired low pressure conditions in the bell jar can be obtained by the use of a vacuum pump attached to one of the air connections on the chamber. A manometer attached to one of the pressure connections of the chamber denotes the amount of pressure inside.

After the desired temperature has been reached and held for the required time the CO_2 may be turned off and the chamber allowed to warm up by the absorption of heat through the insulation. If by this procedure the rate of rise of temperature is insufficient, an electrical heating coil may be inserted and used to increase the gradient.

Precision

The precision of the resistance type thermometers forming part of the chamber is $\pm 1.0^{\circ}C$ and the manometers usually used to measure the chamber pressures are reliable to 0.1 mm of mercury. Using these instruments the operator can usually control the temperatures and pressures within the above limits.

Instrument Problems for the Altitude Chamber

The aeronautical instrument designer is interested in the following factors of instrument operation:

1. Instrument calibration as affected by change in temperature and pressure.
2. The effect of temperature on driving mechanisms (clockwork or electric).
3. Temperature effect on lubrication.
4. Low temperature effect on photographic film and other charts.
5. Effect of temperature on damping mediums.
6. Effect of temperature on pressure diaphragms; metallic and nonmetallic.
7. Efficiency of heat insulation materials.
8. Temperature effect on electric voltage cells.
9. Freezing point of inks and effect of ink flow on various types of charts.

There are other uses for which the apparatus may prove invaluable, such as the study of frosting of goggles, freezing points of airplane engine cooling mediums, etc.

Conclusions

Calibrations and research on instruments under actual conditions are absolutely necessary if any dependence is to be put on instruments employed under conditions of varying temperature and pressure. Through the use of the altitude chamber actual altitude conditions are obtained and instrument irregularities detected and eliminated, thus obviating the necessity for expensive flight research work for this purpose.

The altitude chamber described in this report may be very useful in educational institutions and laboratories where: low temperatures are desired, only a small volume of cooling space is required, low cost is a factor, and safety of operation by unskilled operators must be considered. As the complete equipment is quite portable, it might even be of value for the calibration in the field of instruments used for high altitude flights.

While there is perhaps little room for changes in the general arrangement of the component parts of the present chamber, improvements in efficiency can be effected by the selection of materials of lower heat capacity and conductivity for the instrument support, iron plate and blower. In order to further simplify the construction and operation of the chamber the thermometer at the expansion valve and one of the back pressure gauges may be eliminated. These elements were included in the present chamber mainly for design purposes.

This chamber accommodates all the small N.A.C.A. standard flight research instruments but should it seem desirable at any future date to study temperature effect upon larger instruments or apparatus, a chamber affording several times the existing available space may be constructed without excessive depreciation of operation economy.

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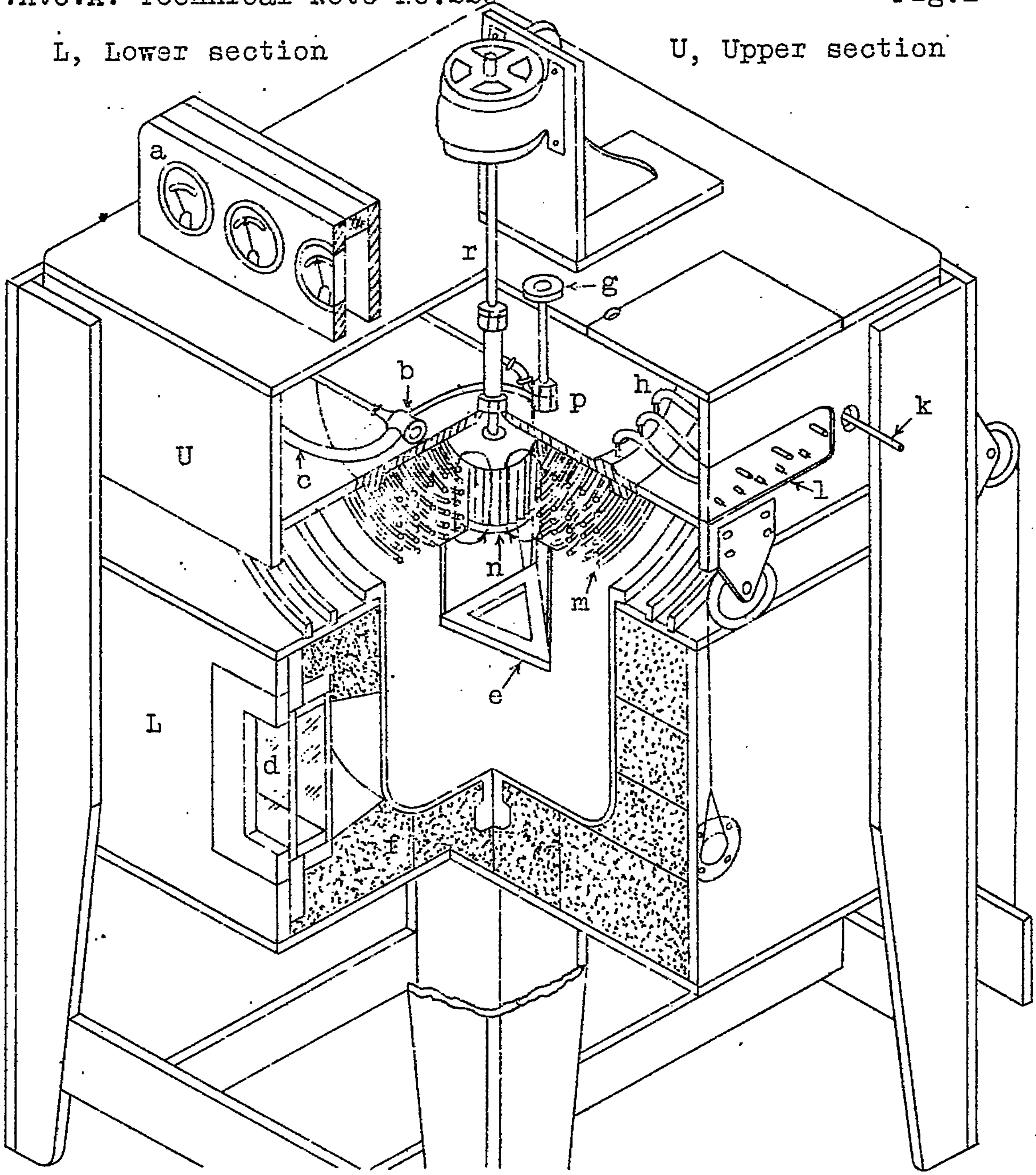

a, Temperature and pressure gage panel.
b, Relief valve.
c, Heat interchanger.
d, Double plate glass observation window.
e, Support for instrument under test.
f, Cork insulation.
g, Main high pressure valve.
h, Space filled with cork insulation.
k, High pressure liquid CO_2 line.
l, Air and electric terminal panel.
m, Copper cooling coils.
n, Air circulating rotor.

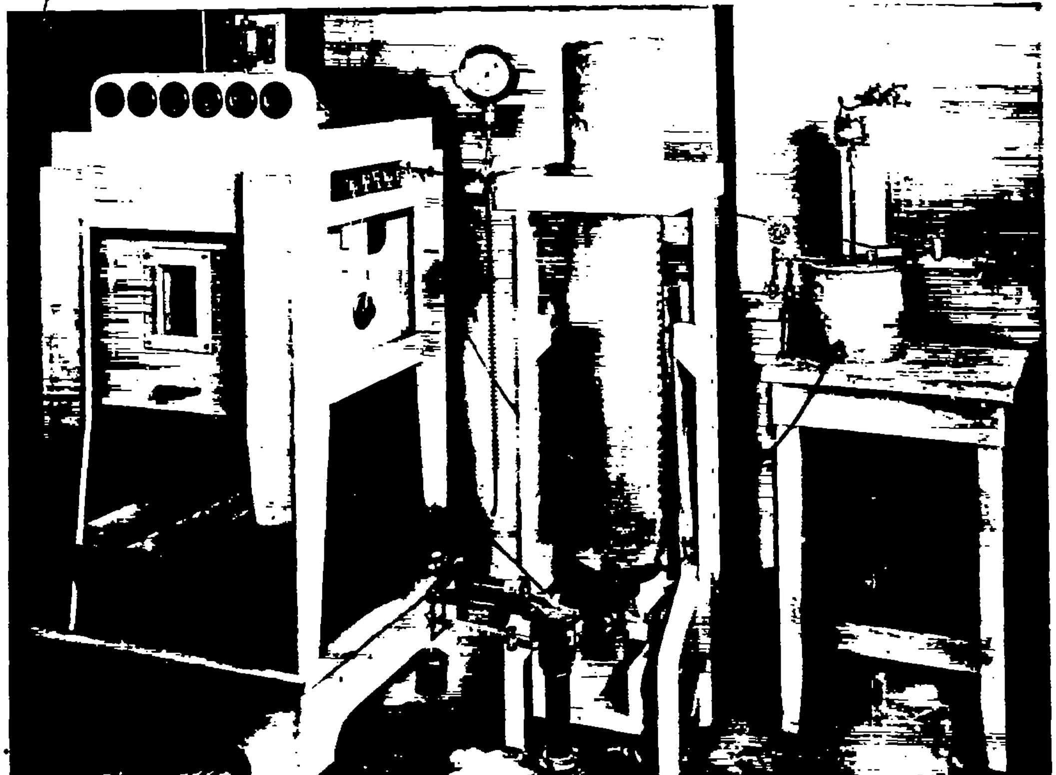

Fig.2 Altitude chamber, CO_2 tank and rack, and low temperature well.

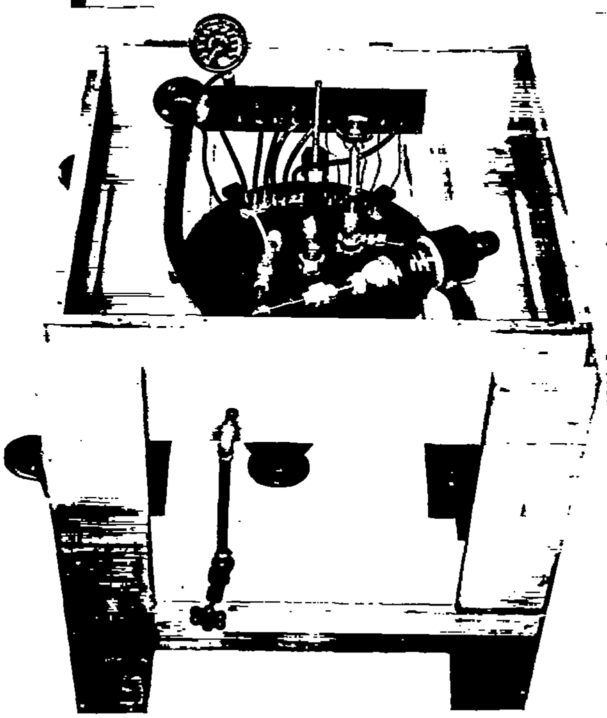

Fig.3 Altitude Chamber, upper section. Arrangement of apparatus on top side of iron plate, less the cork insulation.

Fig.6 Cork insulation used to lag bell jar.

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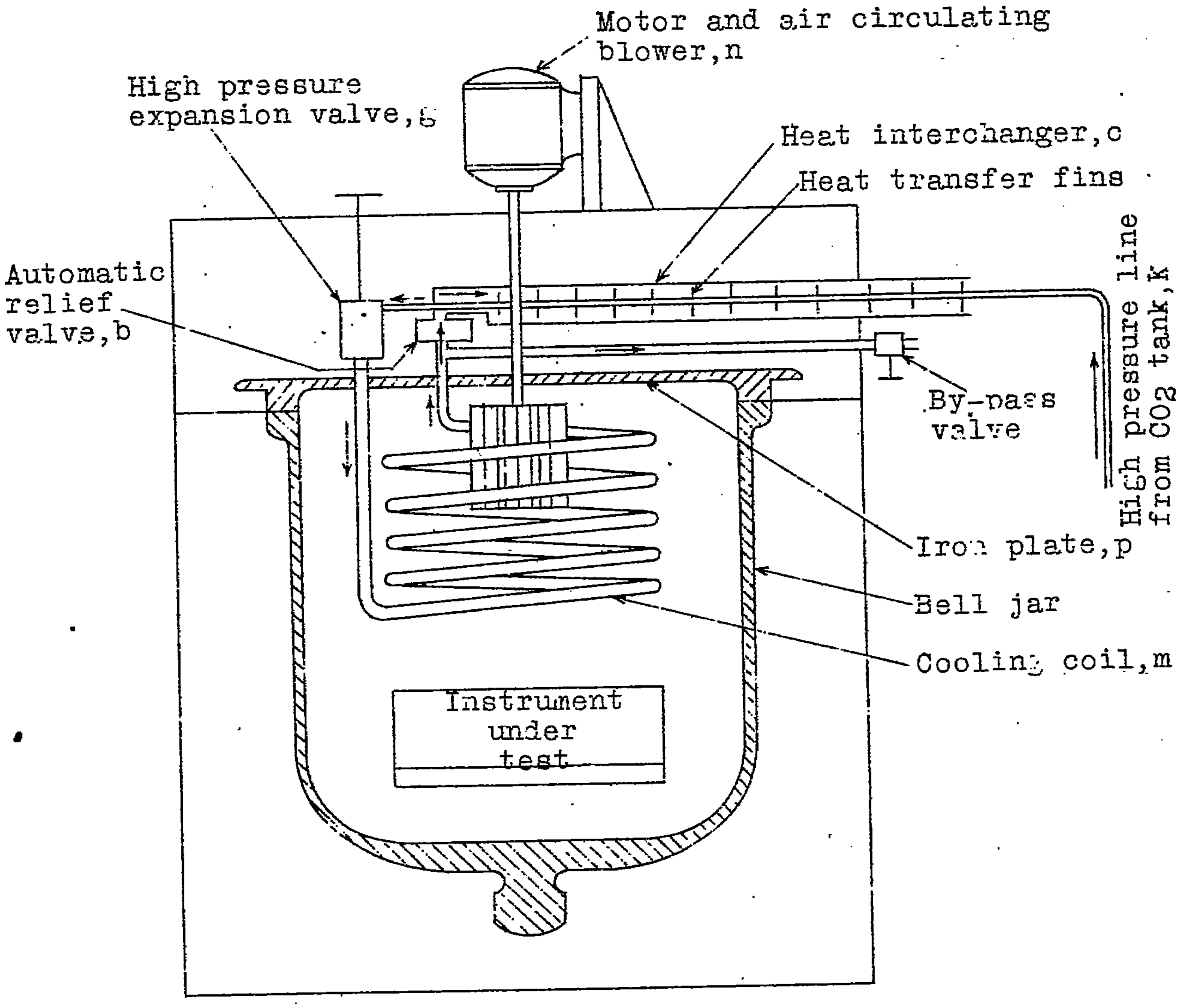

Fig.4 Diagramatic drawing of altitude chamber.

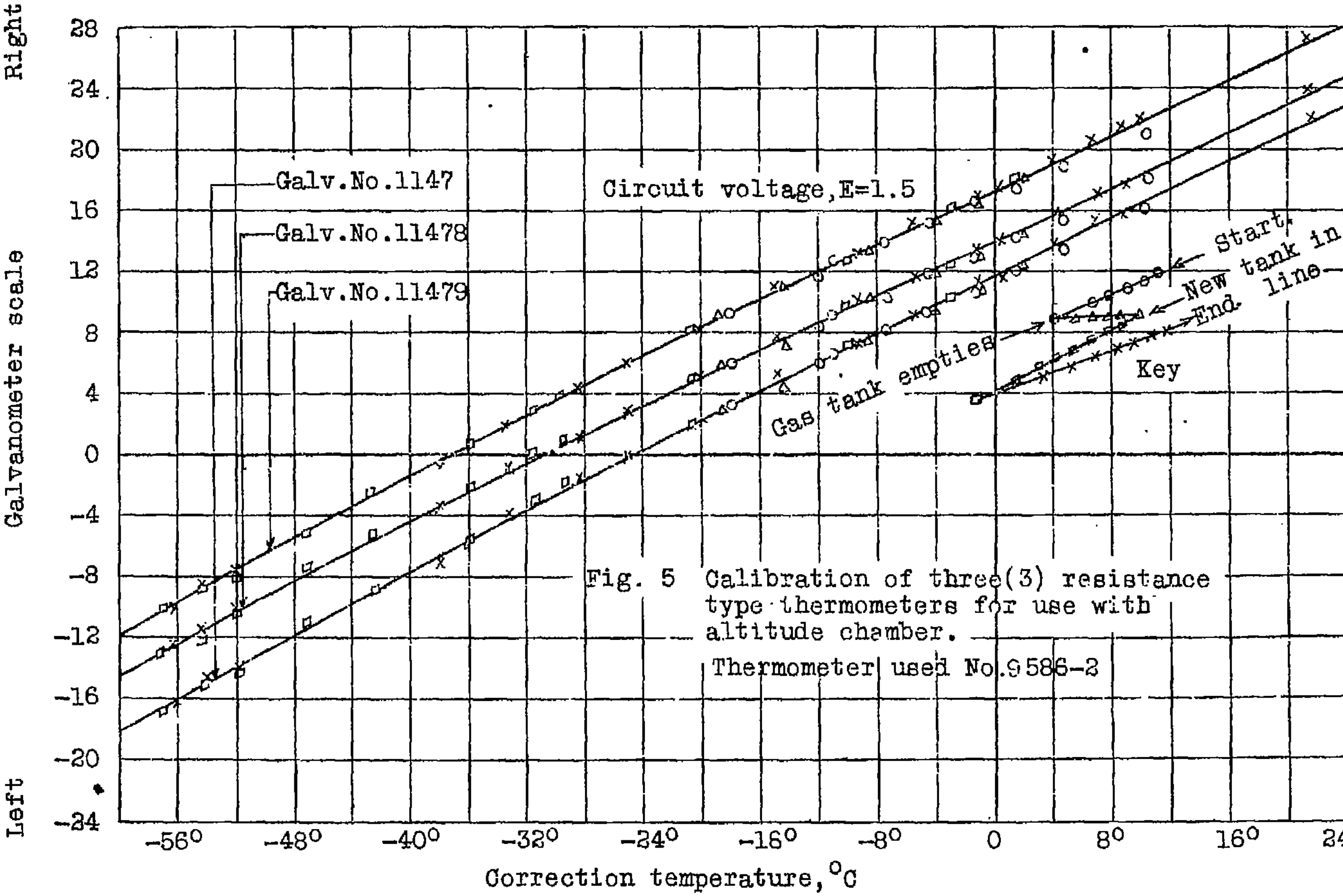

Fig. 5 Calibration of three(3) resistance type thermometers for use with altitude chamber.
Thermometer used No.9586-2

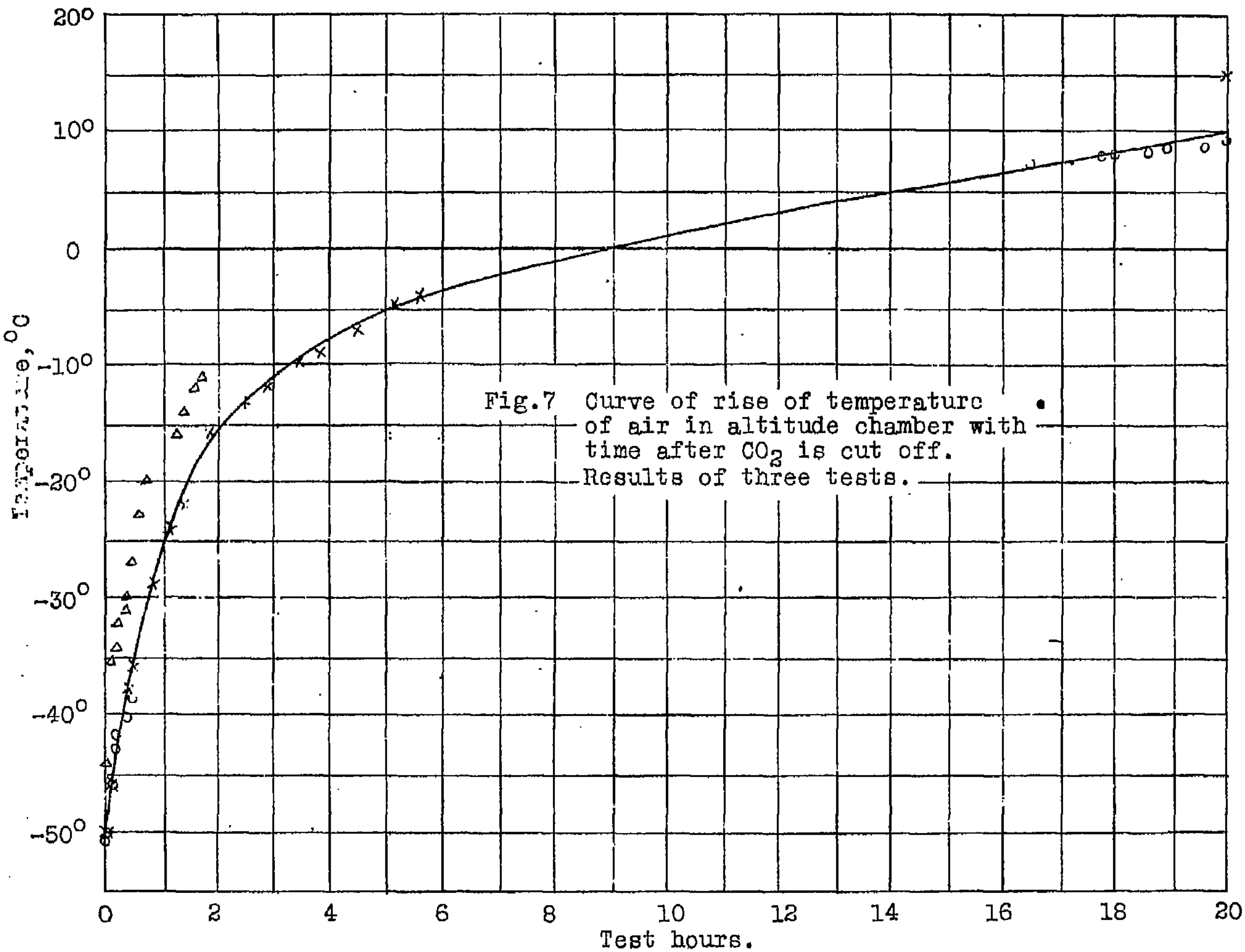

Fig.7 Curve of rise of temperature of air in altitude chamber with time after CO_2 is cut off. Results of three tests.